WILLISTON BASIN PROVINCE (031)

By James A. Peterson

With a description of four continuous-type unconventional plays
by James W. Schmoker

INTRODUCTION

The Williston Basin is a structural-sedimentary intracratonic basin located on the western shelf of the Paleozoic North American craton. The present-day basin occupies a large segment of the northern Great Plains and extends northward into Canada. The basin region is a generally flat lying, moderately dissected plain with minimum topographic relief. The basin is bordered on the east and southeast by the Canadian Shield and the Sioux Uplift. The western and southwestern borders are defined by the Black Hills Uplift, Miles City Arch, Porcupine Dome, and Bowdoin Dome. The United States part of the basin covers approximately 143,000 sq mi with a total sedimentary rock volume of approximately 202,000 sq mi. Sedimentary rocks of Cambrian through Holocene age are present in the basin. Maximum thickness of Phanerozoic rocks is greater than 16,000 ft in North Dakota. The basin began subsiding during Late Cambrian or Early Ordovician time and has continued to subside through the remainder of geologic time, with the subsiding center remaining approximately in the same position in northwestern North Dakota throughout that time.

Sporadic pre-World War II exploration activity took place in the Williston Basin, but the few deeper wells drilled were unsuccessful. Shallow gas was discovered in the Upper Cretaceous Eagle Sandstone on the Cedar Creek Anticline in southeastern Montana in 1916. This resource was subsequently developed and marketed by the Montana Dakota Utilities Company. Following World War II, several major oil companies renewed their interest in the deeper possibilities of the basin. This activity culminated in the 1951 discoveries of the Beaver Lodge field by the Amerada Oil Company on the Nesson Anticline in North Dakota and the Richey and Southwest Richey fields by Shell Oil Company in eastern Montana. Further discoveries followed quickly, on the Nesson Anticline trend by Amerada and other companies and on the Cedar Creek Anticline by Shell, which had contracted with Montana Dakota Utilities Company and the Northern Pacific Railroad for the deep rights on the anticline. Early production on the Nesson Anticline was mainly from Mississippian carbonate reservoirs and on the Cedar Creek Anticlines from Ordovician and Silurian carbonate reservoirs. By the early 1960's

approximately 25 large fields of greater than 15 MMBO had been discovered (table 1), and a major part of the basin's reserves had been found. Intensive exploration by numerous companies continued until the early 1960's when economic factors slowed the pace of activity. With the strong oil price rise in the early 1970's, exploration again intensified and several important large discoveries and many smaller ones were made, particularly in the deeper Red River Ordovician and the Silurian and Devonian reservoirs.

Hydrocarbons have been produced from reservoirs of Cambrian, Ordovician, Silurian, Devonian, Mississippian, Pennsylvania, and Triassic ages. Six main conventional plays were considered for overall hydrocarbon assessment in the Williston Basin, each of which can be subdivided into varying numbers and kinds of subplays: Madison (Mississippian) Play (3101), Red River (Ordovician) Play (3102), Middle and Upper Devonian (Pre-Bakken–Post-Prairie Salt) Play (3103), Pre-Prairie Middle Devonian and Silurian Play (3105), Post-Madison to Triassic Clastics Play (3106), and Pre-Red River Gas Play (3107).

In addition to these main plays and the subplays associated with them, others worthy of study include hydrodynamic plays, fracture belts, salt solution trends, impact structures, basement trends, tight gas reservoirs, and others.

Unconventional continuous-type plays are also important in the Williston Basin. For this province, J.W. Schmoker describes four continuous-type plays: Bakken Fairway (3110), Bakken Intermediate (3111), Bakken Outlying (3112), and Southern Williston Basin Margin-Niobrara Shallow Biogenic (3113).

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CONVENTIONAL PLAYS

3101. MADISON (MISSISSIPPIAN) PLAY

The Madison is a structural-stratigraphic play which is the main play of the basin, containing the largest oil reserves discovered thus far. The play is based on the geographic and stratigraphic occurrence of several marker-defined intervals of porous carbonate reservoirs associated with argillaceous or nonporous lateral carbonate facies and overlain by evaporitic or argillaceous seals. A regional evaporite sequence is present above the main productive reservoir section (Charles salt at the top of the Madison Group). Hydrocarbons are primarily oil with some associated gas.

Reservoirs: Reservoirs are dolomitized carbonate algal-oolitic, crinoidal or bioclastic banks, mainly in the Mission Canyon and Charles Formations.

Source rocks, timing, and migration: The main source rocks are organic-rich dark-gray or black marine shales and shaly carbonates interbedded with reservoir cycles, and organic-rich black shales or shaly carbonates and siltstones in the lower Lodgepole and Bakken Formations at the base of the Madison Group. Source rocks are thermally mature in the center part of the basin but are immature over a large part of the basin flanks and tend to become low in organic carbon on the flanks. Oil generation and migration probably began in Late Cretaceous time, and they continue to the present, with some readjustment during mild Laramide structural movements. Long-distance migration is probably minimal in most accumulations, with the possible exception of some of those in the northeastern part of the basin.

Traps: Traps are gentle folds and closures, some on large anticlinal trends, related to carbonate bank or mound buildups overlain by anhydrite, salt, or shaly beds; updip stratigraphic traps are found on the northeastern flank of the basin, truncated in part by Mesozoic clastics. In some situations, lateral facies changes to argillaceous or evaporitic beds aid in trapping. The largest existing reserves are in accessory structures on major folds (such as the Nesson Anticline and Billings Nose), but a great many smaller traps are present throughout most of the basin. Hydrodynamic-assisted traps are also reported.

Exploration status and resource potential: Depth range of reservoirs is about 5,000 - 13,000 ft. About 390 accumulations exist in the play, 135 are 1 MMBO or more, 20 are greater than 10 MMBO, the largest is about 90 MMBO. Mean pool size is about 3.5 MMBO. The play is moderately well explored. Approximate sizes of the largest

accumulations in the Madison Play are Little Knife, N. Dak., 90 MMBO; Tioga, N. Dak., 70 MMBO; Beaver Lodge, N. Dak., 60 MMBO; Big Stick, N. Dak., 50 MMBO; Poplar East, Mont., 50 MMBO; and Blue Buttes, N. Dak., 40 MMBO. Subplays in the Madison Play include Poplar, Ratcliffe, Midale, Frobisher-Alida, Tilston, Bottineau, Flossie Lake, Whitewater Lake, Virden, Scallion, Charles, A, B, C, and D, State A, Sherwood, Glenburn, Rival, Berentson, Bluell, Kisbey, Mohall, Wayne, Lodgepole, and others. Use of refined seismic data and detailed stratigraphic studies probably will result in additional new field or new pool discoveries. The potential for additional stratigraphic trap accumulations is good, particularly along nearshore and truncation trends on the northeastern and eastern flanks of the basin.

3102. RED RIVER (ORDOVICIAN) PLAY

The Red River (Ordovician) Play (3102) is the second most important existing play of the basin, with the second largest original reserves. The play is based on the geographic and stratigraphic occurrence of carbonate, evaporite, and organic-rich shale cycles in the upper part of the Red River Formation and the overlying, somewhat similar cycles with less rich source beds, in the Stony Mountain Formation.

Reservoirs: The reservoirs are dolomite and dolomitic limestone bioclastic buildups and tidal-flat dolomites.

Source rocks, timing, and migration: Organic-rich marine shales and shaly carbonates cyclically interbedded with carbonate and anhydrite beds in the upper part of the Red River Formation are the primary source rocks. Marine shale beds in the overlying Upper Ordovician Stony Mountain Formation are a secondary source. Source rocks are thermally mature or overmature in all the main part of the basin and tend to pinch out around the basin flanks. Oil generation and migration probably began by Late Paleozoic time. Early trapping was probably mainly stratigraphic. Further migration probably occurred during early Mesozoic and Laramide structural growth.

Traps: Major Red River traps are on the Cedar Creek and Nesson Anticlines. Many smaller accumulations are associated with gently draped rootless folds associated with carbonate buildups and overlying seals, in many cases identified by high-resolution seismic work. Upper Red River anhydrite beds in the main part of the basin are the main seals. Shaly beds in the Silurian, Devonian, and lower part of the Mississippian rocks are the main seals on the Cedar Creek Anticline, where the upper Red River anhydrite beds are absent.

Exploration status and resource potential: Depth range of reservoirs is about 7,000–15,000 ft. There are about 350 existing accumulations in the play; most are less than 20 MMB, largest about 130 MMBO; mean pool size is about 2.3 MMBO. Approximate sizes of the largest accumulations from Red River reservoirs are Pine, Mont., 127 MMBO; Pennel, Mont., 115 MMBO; and Cabin Creek, Mont., 100 MMBO (includes Silurian Reservoir). The largest accumulations of gas and NGL from Red River reservoirs are in North Dakota fields: Beaver Lodge, 140 BCFG and 17 MMBNGL; Tioga, 35 BCFG and 7 MMBNGL; and Charlson, 60 BCFG and 2 MMBNGL.

The Red River (Ordovician) Play can be separated into several subplays, including the Stony Mountain, and the Red River A, B, C, and D cyclic intervals. The play is moderately explored, but good potential remains for numerous additional accumulations in the deeper beds on the Nesson Anticline trend, the Billings Nose, and in isolated carbonate buildup occurrences in the central part of the basin.

3103. MIDDLE AND UPPER DEVONIAN (PRE-BAKKEN–POST-PRAIRIE SALT) PLAY

This play is based on the geographic and stratigraphic occurrence of Upper Devonian cycles of carbonate-evaporite, and dark marine shaly beds throughout most of the basin region. Many of the cycles contain reefoid or mound carbonate buildups, which are commonly dolomitized and porous.

Reservoirs: Dolomite and dolomitized limestone beds in carbonate-evaporite cycles of the Duperow and Birdbear (Nisku) Formations are the main reservoirs; sandstone and carbonate reservoirs in the Three Forks Formation are of some importance.

Source rocks, timing, and migration: Source rocks are the dark marine shale and shaly carbonate beds interbedded with Duperow and Nisku cycles. Source rocks are thermally mature in the central part of the basin but are immature, or in some areas absent, in much of the basin flank region. Oil generation and migration probably began in Early and Late Cretaceous time. Some readjustment of accumulations probably occurred during mild Laramide movements.

Traps: Traps are gentle folds and closures related to carbonate bank buildups overlain by anhydrite or shaly seals. Most accumulations are on regional structural trends such as the Nesson Anticline and related structures and the Billings Nose. Seals are anhydrite beds overlying the main reservoirs, with secondary sealing by argillaceous carbonate beds or shales. Shales of the overlying Three Forks Formation are important regional seals, particularly for Nisku accumulations.

Exploration status and resource potential: Depth range of reservoirs is about 6,000-14,000 ft. There are about 145 existing accumulations in the play; 51 are 1 MMBO or larger; largest is about 70 MMBO. The approximate sizes of the largest accumulations from the Middle and Upper Devonian Play are Beaver Lodge, N. Dak., 68 MMBO and Antelope, N. Dak., 16 MMBO. The main play can be separated into numerous subplays, including the many cyclic intervals of the Duperow, the Birdbear (Nisku), the Dawson Bay, the Souris River, and the Three Forks. The play is moderately explored in parts of the basin but only lightly explored in other areas. Additional Devonian pools will probably be found as deeper drilling progresses in Madison producing areas.

3105. PRE-PRAIRIE MIDDLE DEVONIAN AND SILURIAN PLAY

This play is based on the occurrence of Middle Devonian and Silurian carbonate reservoir units below a regional seal (Middle Devonian Prairie evaporite).

Reservoirs: Middle Devonian Winnipegosis reef or mound dolomitized carbonates, Middle Devonian Souris River and Dawson Bay dolomitized carbonate beds, and dolomitized reefal and tidal carbonate beds of the Silurian Interlake Formation are the reservoirs.

Source rocks, timing, and migration: Moderately organic rich shaly beds of the Upper Ordovician Stony Mountain and the Middle Devonian Souris River Formations are the source rocks. Organic-rich beds of the Upper Ordovician Red River Formation cycles probably are source rocks for some accumulations, by vertical leakage. Source rocks are thermally mature or overmature in the central part of the basin, and in general are not present on the basin flanks. Oil generation and migration probably began by Early Cretaceous time, with some readjustment of accumulations during later mild structural growth.

Traps: Major traps are accessory folds and fault closures on the Cedar Creek and Nesson Anticlines and the Billings Nose. Draped carbonate reef or mound buildups also are traps. Possibly some updip porosity and pinchout traps are present in the Dawson Bay and Souris River beds. The main regional seal is the Middle Devonian Prairie salt and anhydrite beds. Middle Devonian shales and shaly carbonates of the Souris River and Dawson Bay Formations are accessory seals.

Exploration status and resource potential: Depth range of reservoirs is approximately 7,000 15,000 ft. This play is probably moderately explored in shallower drilling areas, but only lightly explored in deeper basin areas. The Winnipegosis reef unit has recently

received considerable attention but is more or less suspended at present, because of deeper drilling costs and the need for high-resolution seismic work. There are about 50 existing accumulations in the play; 17 are 1 MMB or greater in size; largest is about 20 MMBO. Approximate size of the largest accumulations is Charlson, N. Dak., 19 MMBO and 45 BCFG, and Beaver Lodge, N. Dak., 18 MMBO and 91 BCFG. Subplays of this main play include the Winnipegosis reef-bearing unit and the Silurian Interlake carbonates. The incorporation of careful stratigraphic studies will aid greatly in delineation of carbonate reservoir sites and should add significantly to the total resources of this play.

3106. POST-MADISON TO TRIASSIC CLASTICS

This play is based on the geographic and stratigraphic occurrence of Pennsylvanian-Upper Mississippian discontinuous fluvial-deltaic and nearshore marine sandstone and minor carbonate reservoir beds (Big Snowy, Amsden, and Tyler Formations), with associated organic-rich shales, sealed by associated Pennsylvanian, Permian, and Triassic marine and nonmarine redbed shales and evaporites.

Reservoirs: Marine, deltaic, and fluvial discontinuous sandstone beds of the Tyler and Big Snowy Formations are the main reservoirs. Dolomites or dolomitic limestones in the upper Big Snowy (Heath Formation) and the Amsden Formation are secondary reservoirs. Clastic units of Triassic age are targets for non-indigenous oil in the northeastern part of the basin, probably sourced by Mississippian reservoirs.

Source rocks, timing, and migration: Dark-gray to black organic-rich marine shales of the Tyler Formation are the main source. Organic-rich beds of the Heath Formation (Big Snowy) are also a source where that unit is present, in the western part of the basin. Source rocks are mature in the central part of the basin but are immature on the basin flanks. Oil generation and migration probably occurred, mainly into stratigraphic traps, by late Mesozoic or early Tertiary time in the deeper basin area.

Traps: Known traps are on anticlines but have a strong stratigraphic component. Isolated sandstone stratigraphic traps are present in the Tyler Formation and to a lesser degree in the Big Snowy and Triassic sandy section.

Exploration status and resource potential: This play is moderately well explored because of the density of Madison, Red River, and other deeper exploration targets. Stratigraphic trap exploration is necessary for much of any continued exploration. Depth range of reservoirs is about 4,000 - 8,000 ft. There are about 20-25 accumulations

in the play; two are greater than 10 MMBO; largest is about 30 MMBO; about 17 are 1 MMBO or larger. Approximate sizes of the largest accumulations are Dickinson, N. Dak., 28 MMBO, and 8 BCFG; Fryberg, N. Dak., 26 MMBO and 13 BCFG; and Newburg, N. Dak., 43 MMBO. The main play can be separated into several subplays, including the Tyler sands, the Big Snowy sands, the Amsden carbonates, and the Triassic Spearfish sandstones, as well as an unconformity subplay. Careful stratigraphic studies, combined with high-resolution seismic data, are probably necessary for continued exploration, and most of the remaining resources are expected to occur in small accumulations.

3107. PRE-RED RIVER GAS PLAY

This play is based on the occurrence of Ordovician and Cambrian sandstone (or quartzite) reservoirs buried below the zone of oil generation in the deeper part of the basin, along with associated dark marine shale beds.

Reservoirs: Ordovician (Winnipeg and upper Deadwood) and Cambrian (Deadwood) sandstone or quartzite beds, probably fractured, with commonly low matrix porosity, are the reservoirs.

Source rocks, timing and migration: Dark-gray to black marine shales of the upper Deadwood Formation and dark gray to black marine shales interbedded with and overlying Middle Ordovician Winnipeg Sandstone beds are the source rocks. Source rocks are mature to overmature in deeper parts of the basin. Gas generation and migration probably began by Late Cretaceous to early Tertiary time. Migration and accumulation were enhanced by intensification of fracturing in Late Cretaceous and Tertiary time. Dilatation fracturing may be a factor. Much of the inner basin migration probably was toward major structural trends such as the Nesson Anticline and Billings Nose areas.

Traps: Traps are mostly folds along and adjacent to the Nesson Anticline and basinal gentle folds of small closure. Isolated sandstone or quartzite bodies in fracture-intense zones are probably present. Seals are Ordovician and Upper Cambrian shales.

Exploration status and resource potential: Only a few accumulations are presently known. Drilling depths are 12,000 - 16,000 ft. The play is in the early stages of exploration and at present is more or less suspended because of exploration and drilling costs. Gas recoveries on DST have been as high as 3 - 5 MMCFPD or more. The gas is reported to be of low BTU quality. No large accumulations are as yet known from this

play, but the potential exists for significant reserves of deep basin gas if economic factors improve. The play can be subdivided into several subplays, including the Rough Lock and Black Island sands and the sandstones of the upper Deadwood. Regional or local fracture belts also are targets for exploration.

UNCONVENTIONAL PLAYS

Continuous Type

By James W. Schmoker

3110. BAKKEN FAIRWAY PLAY
***3111. BAKKEN INTERMEDIATE PLAY* (HYPOTHETICAL)**
***3112. BAKKEN OUTLYING PLAY* (HYPOTHETICAL)**

The Mississippian and Devonian Bakken Formation of the Williston Basin overlies the Devonian Three Forks Formation and is overlain by the Mississippian Lodgepole Limestone. At its type locality, the Bakken Formation can be divided into three informal but distinct members consisting of an upper black shale, a middle organic-poor gray-brown calcareous siltstone, and a lower black shale that is similar to the upper member. These three members maintain their general character throughout the Montana and North Dakota portions of the Williston Basin.

Reservoir and source rocks: The upper and lower shale members are extremely rich in organic matter. Organic-carbon content averages 12.1 wt. percent for the upper member and 11.5 wt. percent for the lower member. The organic-matter type is predominantly oil-prone, type II kerogen. The thickness of the upper member ranges from zero at subcrops to nearly 25 ft at the depocenter; the thickness of the lower member ranges from zero at subcrops to 45 ft near the basin center.

Vitrinite-reflectance values range from 0.4 percent on the eastern flank of the basin to a maximum of about 1.1 percent, corresponding to present-day depths of roughly 4,500 ft and 11,000 ft, respectively. The total mass of organic carbon within the region where the Bakken Formation is thermally mature is about 10^{14} kg. Available evidence indicates that the Bakken Formation of Montana and North Dakota has generated hundreds of billions of barrels of oil.

The Bakken Formation provides an excellent example of a continuous-type unconventional oil accumulation. In the large region where thermal maturity is sufficient for oil generation, the Bakken Formation forms a continuous, self-sourced reservoir containing an enormous volume of oil in-place. Reservoir quality, measured in terms of matrix porosity and permeability, is poor. Production is controlled by fractures, with the result that production rates and ultimate recoveries of wells exhibit a heterogeneous, "hit or miss" character. Truly dry holes are rare, recovery factors are low, and little water is produced. The reservoir is overpressured.

Given this geologic context, discussion of trap types, trap sizes, migration of hydrocarbons, seals, distribution of traps, and so on, is largely irrelevant to the problem of resource assessment.

Definition of plays: The overall Bakken unconventional continuous-type oil play is bounded on the north by the Canadian border (a political rather than geologic boundary), on the east, northwest, and west by thermally controlled limits of oil generation, and on the southwest by the Bakken subcrop. Within this area, the Bakken Formation is considered to be oil saturated. However, drilling and production data indicate that this entire area cannot be characterized by a single play probability, success ratio, and estimated ultimate recovery probability distribution. Consequently, the overall Bakken play is partitioned into three smaller plays--the Bakken Fairway (along the southwest subcrop), Bakken Intermediate, and Bakken Outlying Plays (3110, 3111, and 3112, respectively).

The internal boundaries separating these three plays are drawn to isolate areas of similar exploration and production results. Qualitatively, overall success decreases from the Bakken Fairway Play (3110) to the Bakken Intermediate Play (3111) to the Bakken Outlying Play (3112).

The causal geologic factors that differentiate the three plays are a subject of debate. Possible causal factors include (1) closer fracture spacing associated with thinning of the Bakken shale members toward the southwest subcrop; (2) better developed fracture systems along a hinge line separating the southwest shelf area and the deep Williston Basin; and (3) systematically increasing thermal maturity levels, and thus more intense oil generation, toward the southwest. The internal boundary of the Bakken Fairway Play (3110) is defined by the vitrinite-reflectance contour of 1.02 percent.

The Antelope field (McKenzie Co., N. Dak.), in the Intermediate Play (3111), warrants special consideration. The Antelope field is on a relatively sharp, southeast-trending anticline. Bakken production from the so-called Sanish Pool of the Antelope field was established in 1953. Typical ultimate recoveries of Sanish Pool wells are considerably higher than those of vertical (and horizontal) wells drilled subsequently in other parts of the Bakken accumulation. However, in the intervening 40 years, no analog to the Sanish Pool has been found. Therefore, data from the Antelope field have been excluded from the assessment of the Bakken Intermediate Play (3111) on the assumption that additional sweet spots equivalent to the Sanish Pool do not exist.

Exploration status: The first significant exploration success in the Bakken Formation occurred in 1953 in the area of the Antelope field. This success triggered additional exploration, but no analogous sweet spots were found. Bakken wells were completed sporadically over the next 25 years, many as bail-out zones for unsuccessful deeper tests.

By the end of the 1970's, the continuous nature of the Bakken accumulation was generally recognized and purposeful Bakken exploration, on the Nesson Anticline in the Bakken Intermediate Play (3111) and along the southwest subcrop in the Bakken Fairway Play (3110), proceeded at a modest pace. In the late 1980's, improvements in horizontal-drilling technology and economics helped fuel what might be termed a horizontal-drilling "boom" along the southwest subcrop. Horizontal wells in other parts of the Bakken accumulation have thus far been mostly economic failures.

The Bakken (Spanish Pool) wells in the Antelope field area have produced about 12 million barrels of oil. As of July, 1993, 161 vertical Bakken wells (excluding the Spanish Pool) have produced 10,320,000 barrels of oil, and 202 horizontal wells have produced 12,233,000 barrels of oil.

Resource potential: Portions of the Bakken Fairway Play (3110) have reached a mature stage of development. However, considering the Bakken accumulation as a whole, many thousands of square miles that are very likely underlain by moveable oil remain undrilled. Production from these untested cells will be controlled by fractures and will be relatively unpredictable on a well-by-well basis. Producing depths for the most part will be between 8,500 ft and 11,000 ft.

The Bakken Play is far from exhausted. Potential additions to oil reserves are measured in the hundreds of millions of barrels, in contrast to the tens of millions of barrels produced to date. Full realization of these potential reserve additions will probably depend upon improvements in technology, economics, and geologic understanding.

3113. SOUTHERN WILLISTON BASIN MARGIN–NIOBRARA SHALLOW BIOGENIC PLAY (HYPOTHETICAL)

Reservoir and source rocks: The Upper Cretaceous Niobrara Formation consists of chalk and calcareous shale that was deposited over a wide area of the Western Interior seaway. Shallow chalk units of the Niobrara Formation have potential for the generation and retention of biogenic gas, which is generated at low temperatures by bacterial breakdown of organic material in an anaerobic environment. Commercial production of Niobrara biogenic gas is well established from many small fields along

the eastern flank of the Denver Basin. The play discussed here (3113) addresses the potential for Niobrara biogenic gas production along the southern flank of the Williston Basin. Niobrara chalk reservoirs, source rocks, and structural influences in the southern Williston Basin margin are similar to those in the eastern flank of the Denver Basin. Porosities are high, organic-carbon content is adequate for gas generation, and shows of biogenic gas have been reported.

The shallow Niobrara biogenic gas fields of the eastern Denver Basin, which number at least 46, are reportedly controlled by localized low-relief structural closure. For this reason, the Niobrara Chalk–Shallow Biogenic Gas Play (3903) of the eastern Denver Basin has been treated in this assessment as a conventional play. However, the close association between source and reservoir rocks, large areal extent, abundant gas shows, low matrix permeability, and abnormal (low) reservoir pressure of the eastern Denver Basin Niobrara Chalk–Shallow Biogenic Gas Play (3903) are characteristics typical of a self-sourced, continuous-type gas accumulation. The large number of small Niobrara producing areas scattered about the eastern Denver Basin could be interpreted as resulting from the uncoordinated development of a continuous-type accumulation. For these reasons, the model of a continuous-type accumulation is chosen for assessment of the Southern Williston Basin Margin–Niobrara Shallow Biogenic Gas Play (3113).

Definition of play: Play 3113 is an unconventional continuous-type play erected to address the possibility that a Niobrara biogenic-gas accumulation, perhaps similar to that of the eastern Denver Basin, exists along the southern margin of the Williston Basin.

The boundary of play 3113 is that of the "southern margin" area of Shurr and Rice (1987, their figure 10), a 30,000 sq mi area regarded by these authors as having the best likelihood for biogenic gas within a much larger potential play area of North Dakota and South Dakota. The geologic factors that combine to make the southern margin area conceptually more favorable are the presence of two chalk units, net chalk thickness exceeding 100 ft, minimal Niobrara outcrop or subcrop, depth of burial of about 1,000 ft, and moderate post-depositional structure development. The minimum possible area of the play is taken as 25 sq mi, which corresponds to the producing area of an analogous field such as Beecher Island in the eastern Denver Basin. The maximum possible area of the play is 90,000 sq mi, which corresponds to the play as mapped plus the possibly prospective areas labeled "southwestern margin", "east-central basin", and "eastern margin" on figure 10 of Shurr and Rice (1987).

The play probability of 0.75 reflects the possibility that the analogy to the eastern Denver Basin is not valid in that some necessary aspect of gas generation, gas retention, or reservoir quality is missing. The success ratio of 0.33 assumed for play 3113 reflects the possibility that structural closure may be a necessary reservoir enhancement for successful wells, even though the gas accumulation is considered to be continuous.

The area of the Goodland field (northwestern Kansas) is regarded as an appropriate analog for Niobrara production parameters in the southern Williston Basin because depths of burial and strata at the top of the Niobrara are similar. Gas in place per acre at Goodland field is roughly one-fourth that at Beecher Island field (Lockridge and Scholle, 1978, their table 1). The estimated-ultimate-recovery fractiles assumed for cells of play 3113 are therefore lower than those associated with better areas of the eastern Denver Basin such as Beecher Island field.

Exploration status and resource potential: On the positive side, production of biogenic gas from chalk of the Niobrara Formation is solidly established elsewhere, and the geologic setting of the Niobrara in the southern Williston Basin margin is similar to that of producing areas. Gas in place within the play area of 30,000 sq mi has been estimated at 21 trillion cubic feet (Shurr and Rice, 1987). Co-mingling of gas from deeper Cretaceous rocks of the Dakota Group, Carlile Formation, and Greenhorn Formation could enhance the economic viability of Niobrara production.

On the negative side, such gas as may be present does not appear to constitute an economically viable resource at the present time. Production has not been established in the play area, and wildcats drilled in South Dakota to date offer little encouragement for commercial yields of Niobrara gas.

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TABLE 1. Ultimate Recovery – fields 15 million barrels of oil or greater in Williston Basin

	Field and date of discovery		Reservoirs (1)						Estimated UltimateRecovery (MMBO)	(BCFG) MMBNGL)
*	Beaver Lodge, N. Dak.	1951	Mm,	D,	Or,	S			130	115	47
	Pine, Mont.,	1952	Or,	Mm					127	20	?
***	Pennel, Mont.	1955	Si,	Or,	Mm				115	?	?
***	Cabin Creek, Mont.	1953	S,	Or,	Mm				115	?	?
	Little Knife, N. Dak.	1977	Mm,	Mb,	Dd,	Or			96	120	15
	Tioga, N. Dak.,	1952	Mm,	Dd,	Or				77	43	17
	Blue Buttes, N. Dak.,	1955	Mm,	Dd,	S,	Os,	Or		53	36	5
	Charlson, N. Dak.	1952	Mm,	Mb,	D,	S,	Os,	Or	52	100	11
	Poplar East, Mont.	1952	Mm,	Mh,	Dn				48	40	
*	Big Stick, N. Dak.	1979	Mm,	Mb,	Dd				46	53	?
	Newburg, N. Dak.	1955	Trs						43	3	
	Fryberg, N. Dak.	1953	Pt,	Mm,	Or				42	18	
	Antelope, N. Dak	1953	Mm,	Dtf,	Dd,	S,	Or		41	16	4
**	Lookout Butte, Mont.	1961							35	?	
	Dickinson, N. Dak.	1958	Pt,	Mm					27	8	
	Glenburn, N. Dak.	1958	Mm						25	0	
	Mondak & Mondak West, N. Dak.	1976	Mm,	Mb,	Dd,	Or			25	10	
	Rough Rider, N. Dak.,	1959	Mm						16	8	
	Sherwood, N. Dak.	1958	Mm,	Mb,	Dd,	S,	Or		23	19-28	3
	Buffalo, S. Dak.	1954	Or						22	40	0
	So. Westhope, N. Dak.	1957	Trs,	Mm					22	4	
	Elkhorn Ranch, N. Dak.	1961	Mm,	Mb,	Or				21	17	2
	North Tioga, N. Dak.	1957	Mm,	Mb,	Os				19	6	?
	Indian Hill, N. Dak.	1978	Mm,	Dn,	Dd,	Os,	Or		18	17	
	Flat Lake, Mont.	1964	Mm						17	17	
	N. Elkhorn Ranch, N. Dak.	1981	Mm,	Mb					17	10	
***	Little Beaver, Mont.,	1957	Or						16	?	
	Rival, N. Dak.	1957	Mm						16	8	
	Wiley, N. Dak.	1958	Mm						16	0	
	Glendive, Mont.	1952	Si,	Or					15	15	
**	T.R., N. Dak.,	1978	Mm,	Trs					15	0	
	Hawkeye, N. Dak.	1955	Mm,	Or					15	4 ?	
*	Capa, N. Dak.	1953	Mm,	S					15	8	

(1) Trs – Spearfish; Pt – Tyler; Mm – Madison; Mb – Bakken; D – Devonian; Dtf – Three Forks; Dn – Nisku; Dd – Duperow; S – Silurian; Os – Stonewall; Or – Red River

Sources: Montana Oil & Gas Commission: North Dakota Geological Survey: NRG Associates.
MMBO – Million barrels oil; BCFG – Billion cubic feet gas; MMBNGL – Million barrels natural gas liquid

* Beaver Lodge area fields, including Beaver Lodge, Capa, Delta, and Hofflund, are reported as 131 MMBO, 380 BCFG, and 46 MMBNGL.

** Billings Nose area fields, including Big Stick, Four Eyes, Frank's Creek, St. Jamobs, T.R., Treetop, and Whiskey Joe, are reported as 80 MMBO, 74 BCFG, and 8 MMBNGL.

*** Cedar Creek Anticline fields, including Cabin Creek, Clear Creek, Little Beaver, Little Beaver East, Lookout Butte, Monarch, and Pennel, are reported as 305 MMBO, 351 BCFG, and 7 MMBNGL.